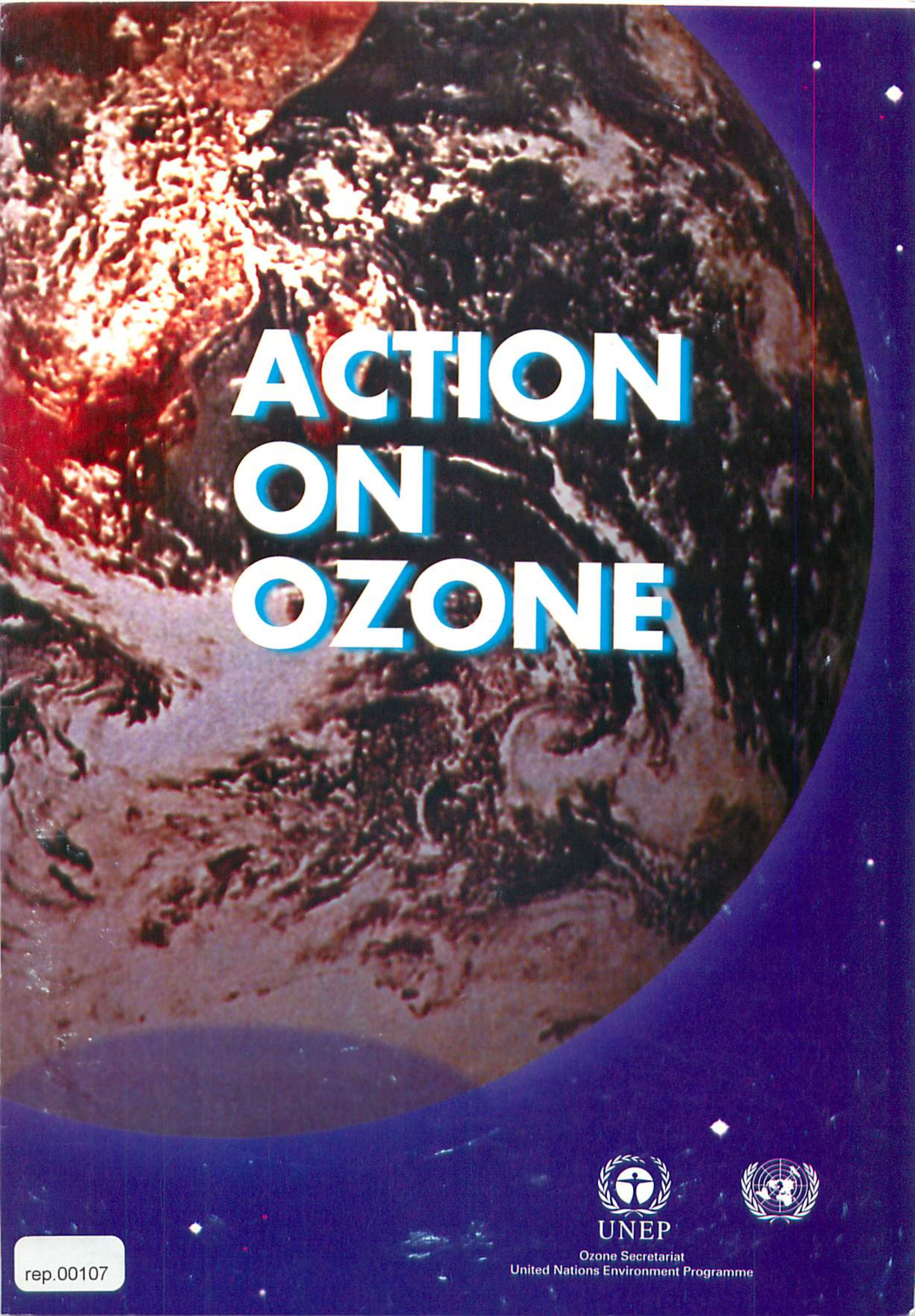


ACTION ON OZONE

UNEP

Ozone Secretariat
United Nations Environment Programme

ACTION ON OZONE

UNEP

Ozone Secretariat
United Nations Environment Porgramme

UNEP

Ozone Secretariat
United Nations Environment Programme
P.O. Box 30552, Nairobi, Kenya

ISBN 92 807 1390 6
November 1996

Produced by
United Nations Environment Programme/Information and Public Affairs Branch
UNEP/IPA

Acknowledgements

Commission of the European Union (EC)

National Aeronautics and Space Administration (NASA),
Goddard Space Flight Center, U.S.A.

National Oceanic and Atmospheric Administration (NOAA),
USA Department of Commerce.

United Nations Environment Programme, Industry and Environment (UNEP/IE),
OzonAction Programme.

United Kingdom, Department of Environment.

World Meteorological Organization (WMO).

Members of the UNEP Scientific Assessment Panel.

Members of the UNEP Environmental Effects Assessment Panel.

Members of the UNEP Technology and Economic Assessment Panel.

Mr. Duncan Brack, Consultant.

Contents

Foreword

The story of the protection of the Earth's stratospheric ozone layer is one of the most inspiring in the annals of international environmental diplomacy.

It deals with a great danger to the health and well-being of peoples and ecosystems around the world: the thinning of the protective ozone layer threatens human skin, eyes and immune systems, damages plants and animals and poses unknown hazards to the planet's climate. It involves a range of highly diverse (and profitable) industrial chemicals which have helped to bring what are now commonplace products – refrigerators, aerosol sprays, insulating and furniture foams – into the homes of millions of families. It brings together on a global stage a vast array of players: scientists, technicians, industrialists, diplomats, journalists, activists, lobbyists, and public servants. All of them working together in pursuit of common aims – the protection of the ozone layer, the achievement of environmentally sustainable development and the building of an effective and equitable global regime to reconcile the aims and aspirations of the peoples and nations of the world. It is a story of brilliant inspiration, painstaking investigation, courageous decisions, hard-fought negotiations and last-minute compromises. And it is not yet over.

This is the third edition of Action on Ozone produced by UNEP. And although the depletion of the Earth's ozone layer has now reached record levels – thanks to the last seventy years of production and use of ozone-damaging chemicals – this is the first edition in which we can say it is reaching its peak. The ozone layer is predicted to start to recover in the next few years, and should be restored to full health by the middle of the next century.

This is the achievement of the regime established by the 1985 Vienna Convention for the Protection of the Ozone Layer and the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. Negotiated against the background of accumulating evidence of ozone depletion from CFCs and related chemicals, these two agreements marked important milestones in the record of international cooperation on the global environment. As fresh scientific evidence has emerged to back up the early hypotheses, and as industrial innovation has developed alternative substances and technologies, governments have agreed to further, stricter, controls on a widening range of ozone-depleting substances. The year 1996 sees the total phase-out, in the industrialized world, of all the chemicals specified in the 1987 agreement, an achievement which was inconceivable a decade ago.

The Montreal Protocol has, rightly, been regarded as a model for other international environmental agreements. It has proved a flexible and adaptable regime. It has helped to bring together scientists, industrialists and governments, with their different but essential viewpoints. It has dealt effectively with the different needs of industrialized and developing countries in meeting a common threat. As UNEP approaches its twenty-fifth anniversary, it is one of our proudest achievements to say: these negotiations, and these agreements, took place under our leadership. There is much that can be learned from the story of the ozone regime of value to other areas of international environmental action, including biodiversity, desertification and climate change. And there is still much to be done in the field of ozone protection. Although there is still scope for tightening the control schedules for the remaining ozone-depleting substances, in order to speed up the recovery of the ozone layer, the ozone regime, as it continues to evolve, is facing new and different challenges. Implementation of the control measures in developing countries; cases of non-compliance; evasion of the controls through illegal trade: all pose new threats to the health of the ozone layer and to the planet beneath it. I am confident that the international community, working with and through UNEP, will rise to meet these challenges, so that we may all continue to strive for a better life for the peoples of the world.

E. Dowdeswell

Elizabeth Dowdeswell
Executive Director
United Nations Environment
Programme

1928 The first CFCs (CFC-11 and -12) are invented in the United States, initially to be used as coolants for refrigeration. Beginning in the 1960s, consumption grows rapidly in developed countries, encouraged by the versatile and favourable properties of CFCs: stable, non-toxic, non-corrosive and non-flammable.

1974 Two scientific papers suggest that CFCs emitted to the atmosphere will diffuse to the upper atmosphere and be broken down to release chlorine atoms, which will catalytically destroy ozone molecules. Nitrogen oxides emitted by high-flying supersonic aircraft are also suggested as a potential cause of ozone depletion.

1 • The Shield in the Sky

All life on Earth depends on the existence of a thin shield of a poisonous gas high in the atmosphere: the ozone layer.

Ozone is a molecule made up of three oxygen atoms. It is an extremely rare component of the Earth's atmosphere; in every ten million molecules of air, about three are ozone. Most (90%) is found in the upper atmosphere (the stratosphere), between 10 and 50 km (6–30 miles) above the Earth's surface. This 'ozone layer' absorbs all but a small fraction of the harmful ultraviolet radiation (UV-B) emanating from the sun. It therefore shields plant and animal life from UV-B, which in high doses can be particularly damaging to natural life. The absorption of UV-B by the ozone layer also creates a source of heat, playing a key role in the temperature structure of the atmosphere.

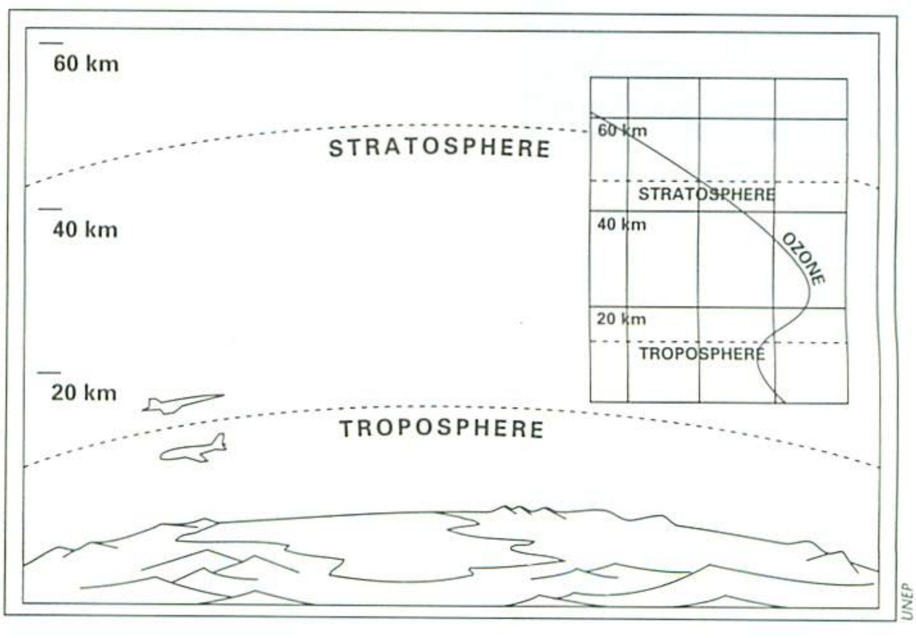
Ozone depletion

Any damage to the ozone layer therefore allows more UV-B radiation to reach the surface of the Earth. Throughout the 1970's and 1980's, scientists began first to suspect, and then to detect, an increasing thinning of the ozone layer. This was accompanied by increases in UV-B reaching the surface; in 1994, UV-B levels were about 8–10% higher than 15 years earlier at 45°N and S (the latitude of Ottawa and Venice in the northern, and Dunedin in the southern, hemisphere), with higher levels towards the poles, particularly in the southern hemisphere. The next chapter explains why this damage to the ozone layer is occurring.

Any rise in the amount of UV-B reaching the Earth's surface has potentially harmful effects on human health, animals, plants, micro-organisms, materials and air quality. In humans, long-term exposure to UV-B is associated with the risk of eye damage: a 1% increase in stratospheric ozone depletion is estimated to result in a 0.6–0.8% rise in the incidence of cataracts (100,000–150,000 additional cases worldwide). UV-B radiation can cause suppression of immune systems, a potentially serious problem in areas where infectious diseases are common. In light-skinned populations, high exposure to UV-B is the key risk factor in the development of skin cancer; experiments suggest that cases increase by 2% for every 1% reduction in stratospheric ozone. Though, moderate exposure, which helps to form vitamin D in the skin, is beneficial. The risk of the more serious melanoma skin cancer also may increase with UV-B exposure, particularly during childhood. Melanoma is now one of the most common cancers among white-skinned people.

Animals are subject to similar effects of increased UV-B. Marine life

Fig. 1.1. The thin layer of ozone in the stratosphere is at its thickest between about 20-40 km up. It also accumulates near the ground in the troposphere, where it is a troublesome pollutant.



1975 UNEP's Governing Council launches a programme of research on risks to the ozone layer; in the United States, a Federal task force concludes that atmospheric release of CFCs is a 'legitimate cause for concern' and that uses of CFC-11 and -12 might have to be restricted. The National Academy of Sciences (NAS) launches an assessment of human impact on the stratosphere.

1977 Thirty two countries agree to a UNEP-brokered World Plan of Action on the Ozone Layer designed to stimulate research; UNEP establishes the Coordinating Committee on the Ozone Layer. The United States Government requires warning labels on CFC-containing aerosols and announces its intention to phase out most CFC use as aerosol propellants. NAS estimates that continued release of CFCs to the atmosphere will deplete the ozone by 14%.

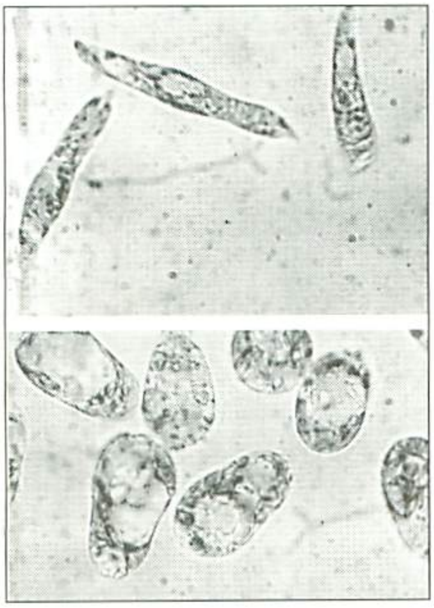

Dr. Donat Hader

Fig. 1.2. Euglena gracilis are a green flagellate organisms which occur in freshwater habitats and are common in lakes, ponds and rivers; Above: these organisms have a spindle form and swim in their elongated form. Below: After UV irradiation the cells twist and turn and then become rounded and cannot swim.

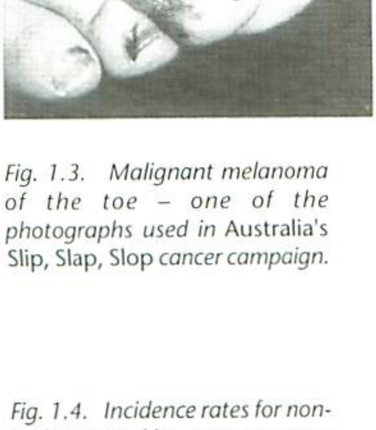

Mark Edwards/Still Pictures

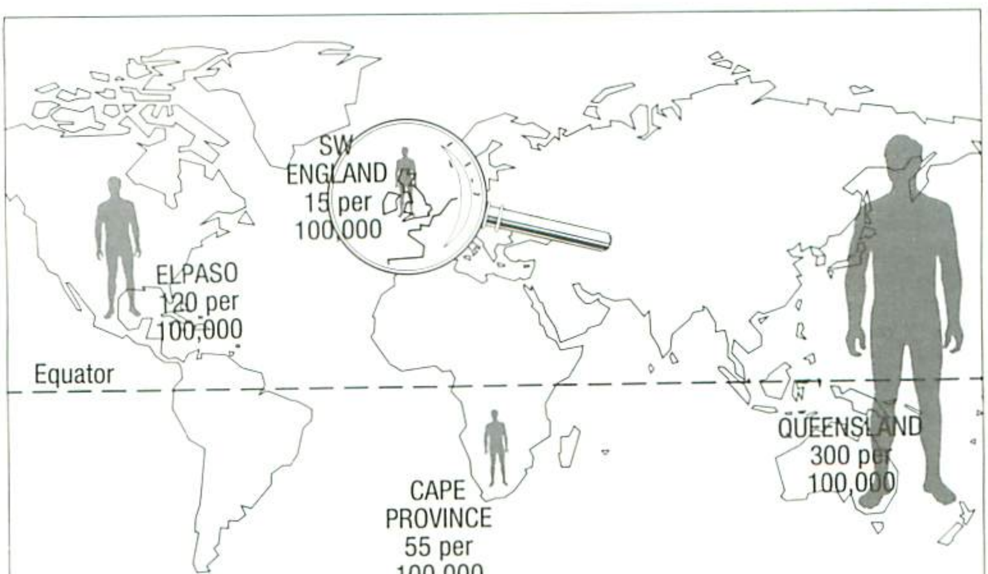
Fig. 1.3. Malignant melanoma of the toe – one of the photographs used in Australia's Slip, Slap, Slop *cancer campaign.*

Fig. 1.4. Incidence rates for non-melanoma skin cancer among white people at the age of 40. The likelihood of developing cancer increases with exposure to the sun and fairness of the skin.

is particularly vulnerable to UV-B, a matter of some concern as more than 30% of the world's animal protein for human consumption comes from the sea. UV-B damages the early developmental stages of fish, shrimp, crab and other water life and reduces the productivity of phytoplankton, the foundation of aquatic food chain. Living mostly near the poles and therefore particularly exposed to the impact of ozone damage, phytoplankton could suffer a loss of 5% in numbers as a result of a 16% level of ozone depletion – which translates into a loss of about 7 million tons of fish per year. Plant growth may also be directly reduced by UV-B radiation, harming crop yields and quality, and damaging forests. Reductions in the productivity of marine and terrestrial ecosystems could in turn reduce the uptake of carbon dioxide (CO_2) thus contributing to global warming.

Synthetic materials such as plastics and rubber, and naturally occurring materials such as wood, are affected by UV-B: the damage caused ranges from discoloration to loss of mechanical strength. Increases in UV-B may limit the lifetime of these materials and require more expensive production processes.

Finally, reductions in stratospheric ozone and the accompanying increases in UV-B radiation have important effects on the troposphere, the lower region of the atmosphere. Its chemical reactivity changes, increasing both production and destruction of ozone, which at this level is a pollutant, causing irritation to eyes and lungs. In many areas it is now increasing in concentration as a by-product of the action of sunlight on emissions from vehicle exhausts, industrial solvents, paints and biomass burning. Changes in the concentrations of other oxidants may also affect the atmospheric lifetimes of other climatically important gases – indicating the possibility of complex and potentially harmful relationships between stratospheric ozone reduction, tropospheric chemistry and climate change.



Action On Ozone (1991)

1979 A number of developed countries start to impose legal controls on CFC-11 and -12 production or use; in the United States, the NAS estimates eventual ozone depletion of 16.5%, or up to 30% of CFC production and release continues to grow, and calls on the United States Government to lead a world effort to control CFCs.

2 • The 'Hole' in the Layer

Miracle substances

Concern began to be expressed in the early 1970s that the ozone layer was vulnerable to damage by the release of chemicals known as halocarbons, compounds containing chlorine, fluorine, bromine, carbon and hydrogen. The most common ozone-depleting substances (ODS) were thought to be the family of chlorofluorocarbons, or CFCs, first produced in Belgium in 1892. CFCs were discovered, by General Motors chemists in the United States in 1928, to be an effective refrigerating fluid. As CFC is stable and non-toxic, cheap to produce, easy to store and highly versatile, proved themselves an immensely valuable range of industrial chemicals. They came to be used for refrigeration, air conditioning and blowing foams, as solvents, sterilants and aerosol propellants. Major new uses were found for CFCs each decade, and world production, concentrated largely in the United States of America and western Europe, doubled roughly every five years until 1970.

As scientific knowledge developed, other families of chemicals – halons, carbon tetrachloride, methyl chloroform and methyl bromide – also came to be identified as ozone-depleters. Some of the CFC substitutes ultimately developed also damage the ozone layer, but at much lower rates.

CFCs' stability leads to their ozone-depleting properties. When released into the lower atmosphere – e.g. through the use of an aerosol spray, or a cleaning solvent, or through leakage of a refrigerant – CFCs persist long enough to diffuse up into the stratosphere, where they are broken apart by solar radiation to release chlorine atoms, which react strongly with ozone molecules. The chlorine

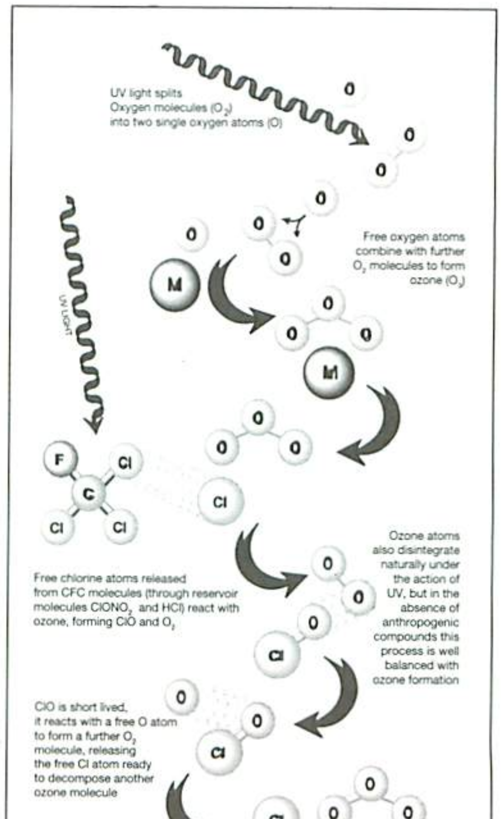


Fig. 2.1. Schematic sequence of the destruction of ozone by active chlorine (Cl) released from a CFC-12 molecule.

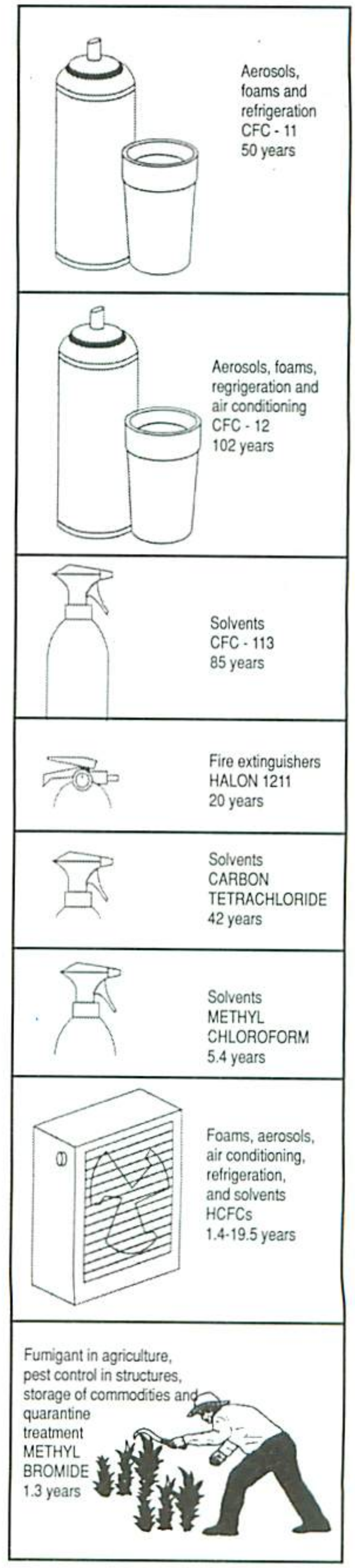
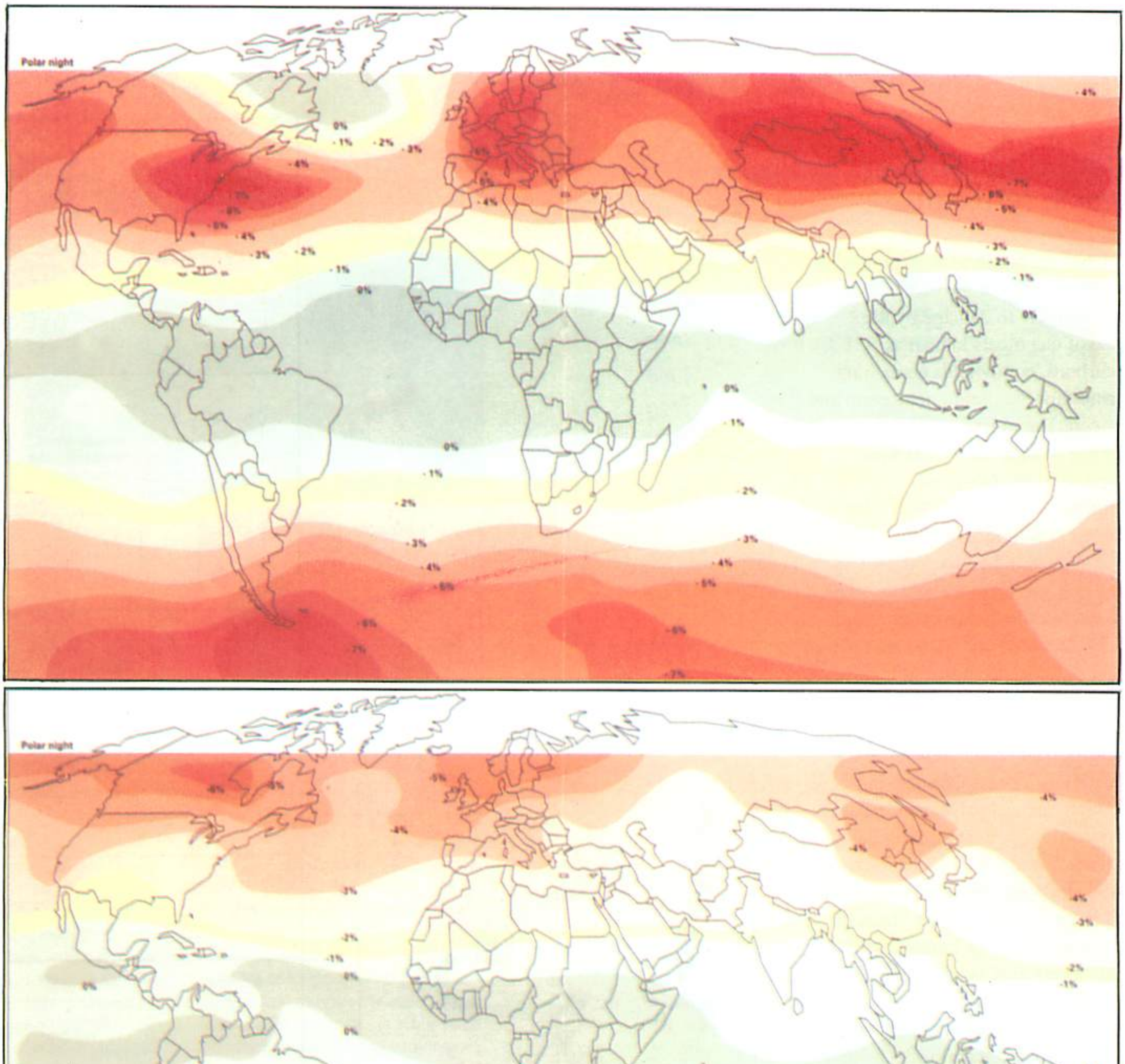


Fig 2.2. Important ozone depleting substances controlled by the Montreal Protocol, their uses and life.

***1980** Seven developed countries and the European Community call for an international convention to protect the ozone layer. The EC freezes production capacity and begins to limit use in aerosols. The United States Environmental Protection Agency proposes the first legal controls on non-aerosol uses of CFCs. CFC manufacturers form the Alliance for Responsible CFC Policy, which argues that further regulation of CFCs would be premature in the absence of hard evidence of ozone depletion.*



NASA pers. comm ©tolarski 1992

Fig. 2.3. THE OZONE LAYER
The two world maps show average trends of ozone decline in the years from 1978 to 1991. Trends are measured in % of decline per decade. The top map shows trends for December to March, the bottom map shows trends for May to August.

1981 UNEP's Ninth Governing Council proposes to begin work on the elaboration of a legal framework convention for ozone layer protection and establishes an ad hoc working group of legal and technical experts for this purpose.

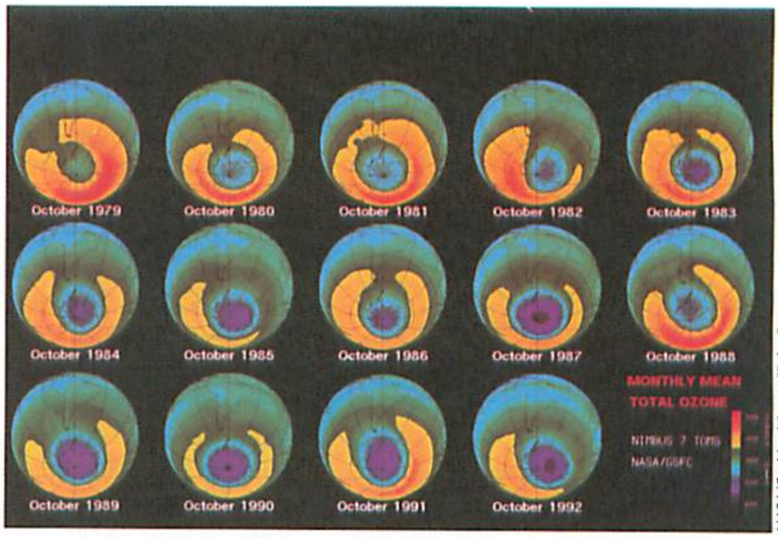
1982 The UNEP working group begins to elaborate a framework convention for the protection of the ozone layer, based on a draft proposal from Finland, Norway and Sweden. The United States National Aeronautical and Space Administration (NASA) estimates that eventual ozone depletion due to CFC use will be less than previously thought, between 5 and 9%.

oxide formed then undergoes further reactions which regenerate the original chlorine, allowing the process to be repeated many times; each chlorine atom can destroy an estimated 100,000 ozone molecules before it is removed from the stratosphere. Although UV radiation continually recreates ozone from oxygen, the presence of chlorine speeds up ozone destruction but not its creation, reducing the overall concentration of ozone. Similar reactions take place between bromine and ozone.

The ozone 'hole'

These reactions are particularly intense within the stratospheric clouds that form above Antarctica in the extremely cold night of the southern hemisphere winter. Reactions which occur on the surfaces of ice particles within the clouds release chlorine and bromine in active forms that accumulate through the winter. When the sun rises in the spring the clouds break up to release active chlorine and bromine which rapidly destroy ozone. The result is the 'ozone hole', an area of sharp decline in ozone concentrations over most of Antarctica for about two months during the southern hemisphere spring.

Stratospheric air above the Arctic is generally warmer and less confined than over the Antarctic, and fewer clouds form there. Arctic ozone depletion is therefore less severe, though in recent years it has proved worse than expected. Polar ozone depletion is accelerated by atmospheric circulation, which moves CFCs in the stratosphere away from the tropics towards both poles.



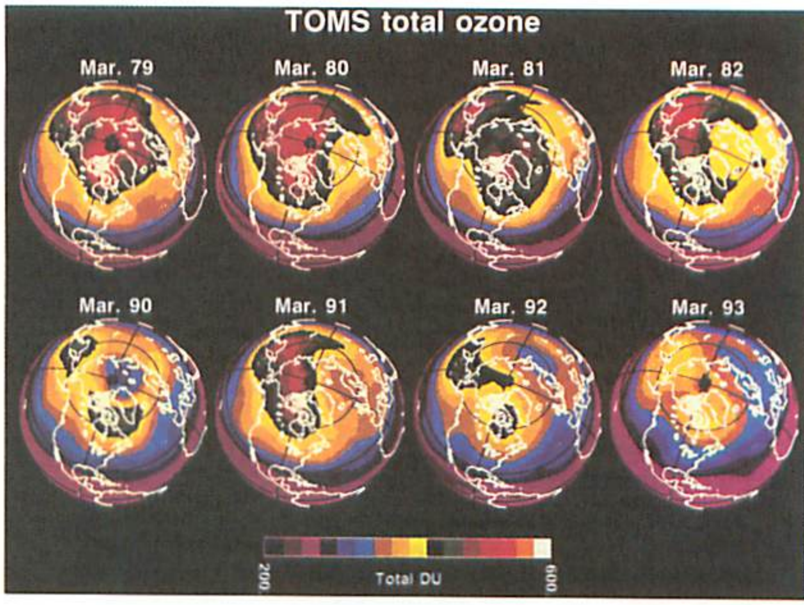
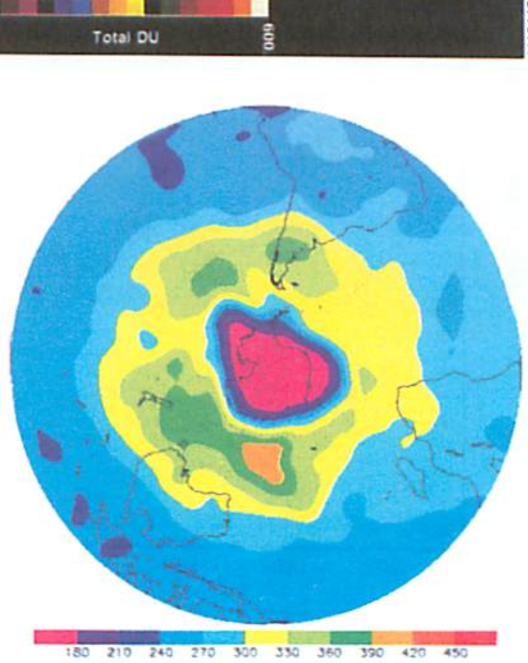


Fig. 2.4. Monthly Antarctic (South Pole) ozone levels in October during a 14-year period, 1979-1992. The ozone measurements were taken by NASA's Total Ozone Mapping Spectrometer (TOMS), Goddard Space Flight Center.

Fig. 2.5. Monthly average ozone levels in March in the Arctic (North Pole) during a 14-year period. The first four years, 1979-1982 and the last four years 1990-1993 are recorded by NASA's Total Ozone Mapping Spectrometer (TOMS).

Fig. 2.6. The Antarctic ozone hole taken from NOAA's TIROS Operational Vertical Sounder (TOVS) on 7 October 1995.



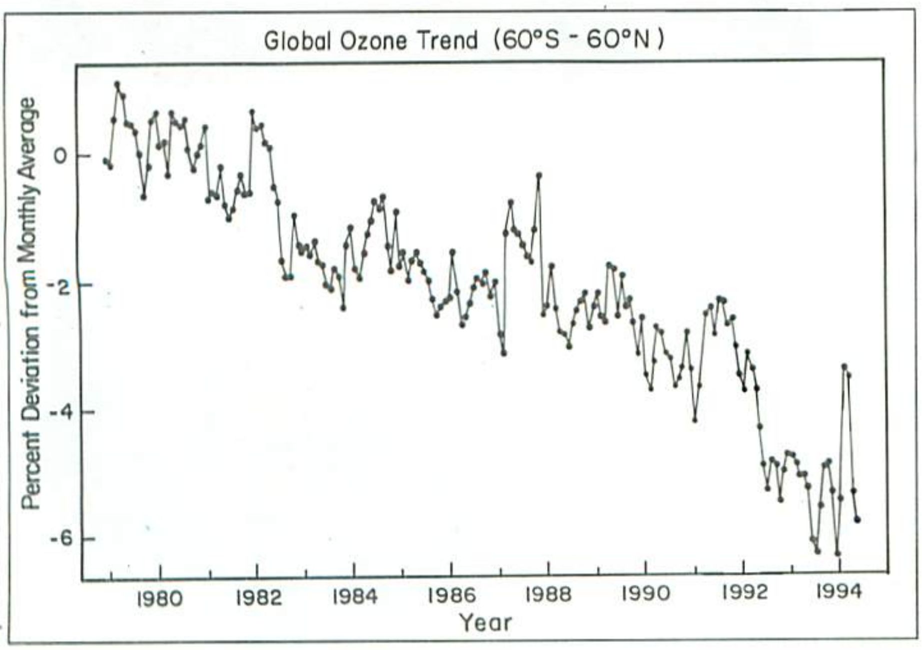
1985 The Vienna Convention for the Protection of the Ozone Layer is adopted by 28 countries. The Convention requires no restrictions on ozone-depleting substances, but allows for the future elaboration of specific controls; the resolution adopted along with the Convention lays the foundation for further work on a protocol on CFC control. Two months later Joe Farman, of the British Antarctic Survey, publishes a paper showing sharp seasonal depletion of the ozone layer over Antarctica – the ozone 'hole'.

Observations of stratospheric ozone concentrations since the 1970s have confirmed the evidence of gradual ozone depletion, with seasonal variations. Since 1979, ozone concentrations have fallen by about 4% per decade at mid-latitudes (30°–60°) in both the northern and southern hemispheres. The losses are largest during the winter and spring. In the spring of 1995, stratospheric ozone concentrations over Europe were 10 to 12% lower than in the mid-1970s, and over North America 5 to 10% lower, although at times as much as 20% lower in some places. (The tropics (20°N–20°S) experienced little or no ozone loss.) UV-B intensities increased accordingly; 1992–1993 saw the first reported examples of persistent increases over densely populated regions in the northern hemisphere. In 1992 southern South America experienced a doubling of UV-B radiation following a 50% fall in ozone as the area of ozone depletion around the South Pole rotated to cover the tip of the continent.

The Antarctic ozone holes of 1992 and 1993 were the most severe on record, with ozone disappearing completely at altitudes of 14 to 19 km in October 1992 and 1993. It is believed that particles from the volcanic eruption at Mount Pinatubo in 1991 accelerated ozone destruction. The 1995 ozone hole, though neither the deepest nor the largest on record, lasted the longest. It covered an area greater than 10 million km² (roughly equivalent to the surface area of Europe) for 77 days, compared to 63 days in 1993, and just 25 days in 1985; it covered more than 20 million km² on 39 days.

Ozone losses above the Arctic have been lower, with a total loss of about 10 to 20% compared to 1979. The Arctic winter of 1994–1995, however, was exceptionally cold, and ozone concentrations in March 1995 were 20 to 30% below normal. The winter of 1995–1996 was even colder, and ozone concentrations over Britain, for example, fell by almost 50% in the first week in March, the lowest ever recorded over the United Kingdom. This unexpected recurrence of cold winter temperatures in the stratosphere may itself be due to cumulative ozone destruction, or possibly to climate change; in either case, ozone losses over the northern hemisphere may be more severe than anticipated in the near future.

Fig. 2.7. Global Ozone Trend over 60° South - 60° North from 1979 - 1984.



Report of the UNEP Scientific Assessment Panel (1994)

1987 After several rounds of negotiations, 46 countries adopt the Montreal Protocol on Substances that Deplete the Ozone Layer. The Protocol requires an eventual 50% cut in consumption of five CFCs by the end of the century, and a freeze in the consumption of three halons, with a ten-year grace period for developing countries to enable them to meet their basic domestic needs; the controls are to be reassessed at least every four years. During the year, a number of European countries legislate to restrict the use of CFCs as aerosol propellants.

3 • Saving the Ozone Layer

Beginnings

Since its foundation, the United Nations Environment Programme (UNEP) has been concerned with the protection of the ozone layer. The United Nations Conference on the Human Environment in Stockholm in 1972, which gave birth to UNEP, addressed the topic of ozone depletion.

The first major statement of scientific concern over ozone depletion from CFCs came in 1974, prompted by James Lovelock's discovery of the presence of CFCs in the atmosphere all around the world. Sherwood Rowland and Mario Molina's research (for which they were later to win the UNEP's Global Ozone Award and Nobel Prize in chemistry), paved the way to the now thorough understanding of the processes by which CFCs diffuse up into the stratosphere, are broken apart and destroy ozone molecules.

Although the hypothesis was initially controversial, the extent and growth of CFC use worldwide was enough to trigger calls for urgent action. In March 1977, experts from 32 countries met in United States in Washington D.C. to adopt the 'World Plan of Action on the Ozone Layer'. The Plan included research into the processes that control ozone concentrations in the stratosphere; the monitoring of ozone and solar radiation; the effect of ozone depletion on human health, ecosystems and the climate; and the development of ways to assess the costs and benefits of control measures. UNEP was the coordinating agency, assisted by the Coordinating Committee on the Ozone Layer, made up of experts from intergovernmental agencies, governments and industry.

In the United States, the Washington D.C. meeting reinforced existing concerns over the impact of emissions from supersonic aircraft. An effective public campaign led to regulations prohibiting the use of CFCs as aerosol propellants in non-essential applications by 1978; Canada, Sweden and Norway soon followed. Production of CFC-11 and -12 in the United States fell from 46% of the world total in 1974 to 28% by 1985 as a result. Alternative propellants were rapidly introduced and often proved more economic than the original CFCs. After 1982, however, CFC production in the United States started to accelerate once more, as use increased sharply in vehicle air-conditioning and foam-blowing.

In 1980 the European Community agreed to freeze production capacity of CFC-11 and -12 and reduce CFC use in aerosols by at least 30% from 1976 levels by the end of 1981. Since production capacity of the European Community (EC) was at the time substantially above consumption levels, a capacity freeze hardly contributed much to the control of CFC emissions. The combined effect of the various measures taken, however, was enough to reduce public pressure for further controls. UNEP was left with the responsibility of keeping the issue of ozone depletion on the international agenda.

The Vienna Convention for the Protection of the Ozone Layer

In 1981 UNEP's Governing Council established an Ad Hoc Working Group of Legal and Technical Experts for the Elaboration of a Global Framework for the Protection of the Ozone Layer. The Group's aim was to secure a general treaty to tackle ozone

1995 Nobel Chemistry Prizes


UNEP/IE, Ozone Secretariat

Fig. 3.1 a. Dr. Paul Crutzen, in 1970, Max Planck Institute, showed that the nitrogen oxides play an important role in controlling the natural balance of ozone.


UNEP/IE, Ozone Secretariat

Fig. 3.1 b. Dr. Mario Molina, MIT, in 1974 published with Dr. Sherwood Rowland a widely noted article in Nature *on the threat to the ozone layer from Chlorofluorocarbons (CFCs).*

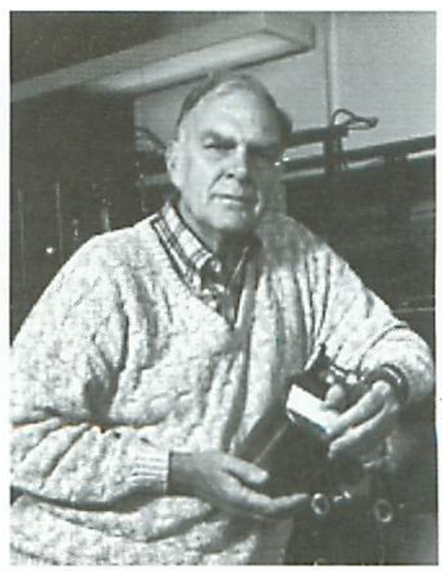
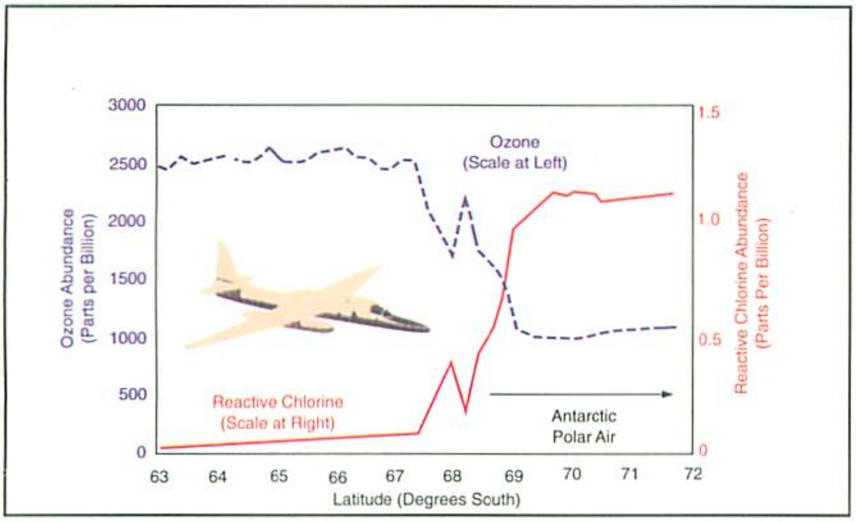

UNEP/IE, Ozone Secretariat

Fig. 3.1 c. Dr. Sherwood Rowland, Professor Emeritus, Department of Chemistry, University of California, Irvine, whose paper with Dr. Mario Molina sparked intensified research on ozone.

1988 The scientific Ozone Trends Panel, sponsored by international agencies and United States research bodies, concludes that CFCs are responsible for the Antarctic ozone hole. UNEP-administered international assessment panels are created under the Montreal Protocol to review the latest information on scientific, environmental, technical and economic aspects of ozone depletion. DuPont becomes the first CFC-producing company to announce that it will phase out CFC production; Northern Telecom, Seiko and Epson become the first multinational companies to announce phase-out goals for CFC consumption. Sweden decides to phase out CFCs by the end of 1994.

depletion. The first step of a framework agreement was expected to be relatively easy to achieve, but differences between the proponents of control measures on the use of CFCs in various sectors (such as the United States) and supporters of caps on existing production capacity (such as the EC) led to four years of hard work and negotiation.

The Vienna Convention for the Protection of the Ozone Layer was ratified by 28 countries in March 1985. It contained pledges to cooperate in research and monitoring, to share information on CFC production and emissions, and to pass control protocols if and when warranted. Although it contained no commitment to take any action to reduce CFC production and consumption, the Vienna Convention was nevertheless an important milestone. Nations agreed in principle to tackle a global environmental problem before its effects were felt, or its existence scientifically proven – probably the first example of the acceptance of the 'precautionary principle' in a major international negotiation.



Report of the UNEP Scientific Assessment Panel (1994)

Fig. 3.2. Measurements of ozone and reactive chlorine from a flight into the Antarctic Ozone Hole.

Dr. J. Foot MCF

Fig. 3.3. The United Kingdom Meteorologic Office Hercules aircraft equipped for atmospheric chemistry and aerosols measurements.

The Montreal Protocol on Substances that Deplete the Ozone Layer

The Vienna Conference also adopted a resolution empowering UNEP to convene negotiations for a protocol to the Convention, to be signed if possible in 1987. Progress in this second set of negotiations was given a boost by the publication, just two months after Vienna, of the findings of members of the British Antarctic Survey led by Dr. Joe Farman. This was the famous 'ozone

1989 The Montreal Protocol enters into force. At their first meeting, parties agree to a non-binding statement calling for CFCs to be phased out as soon as feasible. Thirteen developed countries announce their intention to phase out the eight controlled substances by 1997. First synthesis of UNEP's Science, Environmental Effects, Technology and Economic Assessments.

1990 Meeting in London, parties agree to phase out CFCs and halons completely by the year 2000, and add phase-out dates for other CFCs, methyl chloroform and carbon tetrachloride. Parties agree to create a mechanism to provide financial and technical assistance to developing country parties, including a Multilateral Fund. Finland launches a fund for non-party countries.

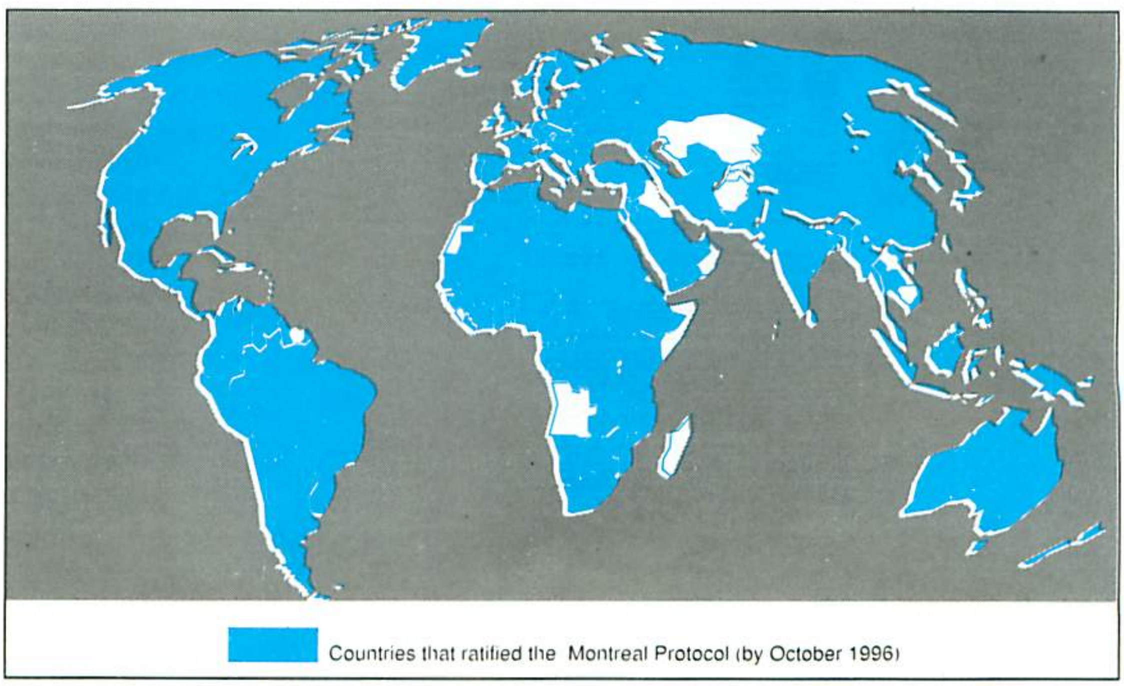
hole' paper, revealing for the first time the existence of dramatic declines in ozone concentrations over the Antarctic in the spring. In fact United States satellite observations had already detected this in the late 1970s, but the unexpected findings were discarded as suspected instrument error. Although the cause was still then unknown, suspicion fell on CFCs.

By comparison with the protracted negotiations over the Vienna Convention, negotiations on the control protocol proceeded remarkably quickly and achieved far more than was initially thought possible. On 16 September 1987, 46 countries signed the Montreal Protocol on Substances that Deplete the Ozone Layer. Since 1995 the United Nations General Assembly has declared 16 September as the International Day for the Preservation of the Ozone Layer to commemorate the signing of the Montreal Protocol.

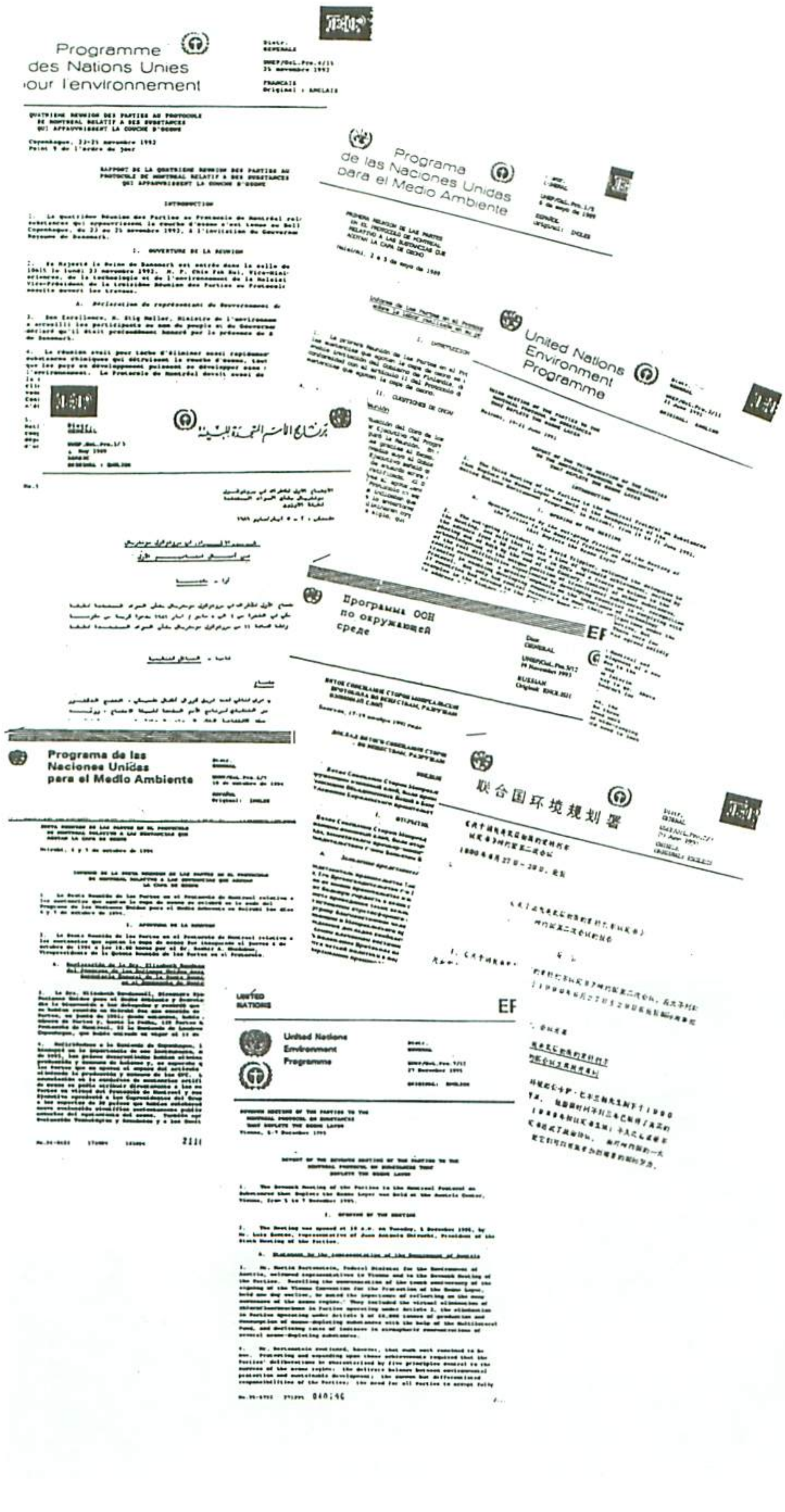
The Montreal Protocol required 50% cuts from 1986 levels in both production and consumption of the five main CFCs by 1999, with interim reductions. Production and consumption of the three main halons was frozen at 1986 levels from 1993.

Although these reductions could be attacked as either too little (if the ozone depletion hypothesis was believed) or too much (if it was not), the agreement marked an important political and psychological breakthrough. And once again science validated the negotiators' actions. March 1988 saw the release of the report of the Ozone Trends Panel, reviewing evidence particularly from the United States Antarctic expeditions in 1986 and 1987, and providing, for the first time, convincing evidence of the linkage between ozone depletion and CFCs. Opposition to the principle

Fig. 3.4. Countries that have ratified the Montreal Protocol (1987).



__1991__ An interim Multilateral Fund becomes operational with a three-year budget of $240 million – UNEP, UNDP and the World Bank are the initial implementing agencies, later joined by UNIDO. UNEP launches the OzonAction Programme. Assessment panels operating under the Protocol conclude that even more stringent controls than those agreed by parties in 1990 are needed, including restrictions on the use of HCFCs. The panels also conclude that technologies are available to replace virtually all uses of controlled substances, and that the phase-out process is less expensive than previously predicted.



of controls on ozone-depleting substances then largely collapsed, and industry started to concentrate resources on the development of non-ozone depleting alternatives to CFCs.

An important feature of the Montreal Protocol was the flexibility designed into it to allow for its further development in the light of evolving scientific knowledge and technological developments. Even before it entered into force on 1 January 1989, plans were being made to strengthen its provisions, advancing the phase-out schedules for the CFCs and halons it specified, and adding further ozone-depleting chemicals.

The Protocol has now been subject to three sets of adjustments to the control measures (agreed at the 1990, 1992 and 1995 Meetings of the Parties), accelerating the phase-out schedules for ozone-depleting substances. It has also been subject to two amendments. The London Amendment (1990) added methyl chloroform, carbon tetrachloride and a further range of CFCs to the phase-out schedules and established a mechanism for financial and technical assistance to developing country parties. The Copenhagen Amendment (1992) added hydrochlorofluorocarbons (HCFCs), hydrobromofluorocarbons (HBFCs), and methyl bromide to the phase-out schedules and formally created the Multilateral Fund as the route for financial transfers to developing countries. The main features of the regime established by the Montreal Protocol are examined in the next chapter, and their impact in the following one.

Fig. 3.5. Reports of the meetings of the Parties to the Montreal Protocol.

1992 Meeting in Copenhagen, parties to the Montreal Protocol agree to speed up phase-out schedules for already controlled substances and to control new substances for developed countries – HCFCs, HBFCs and methyl bromide. A number of developed countries adopt faster timetables for phase-out of controlled substances. Mexico (a developing country) announces that it is prepared in principle to phase out CFC use by 2000, the existing deadline for developed countries. The Multilateral Fund is officially established.

4 • The Montreal Protocol

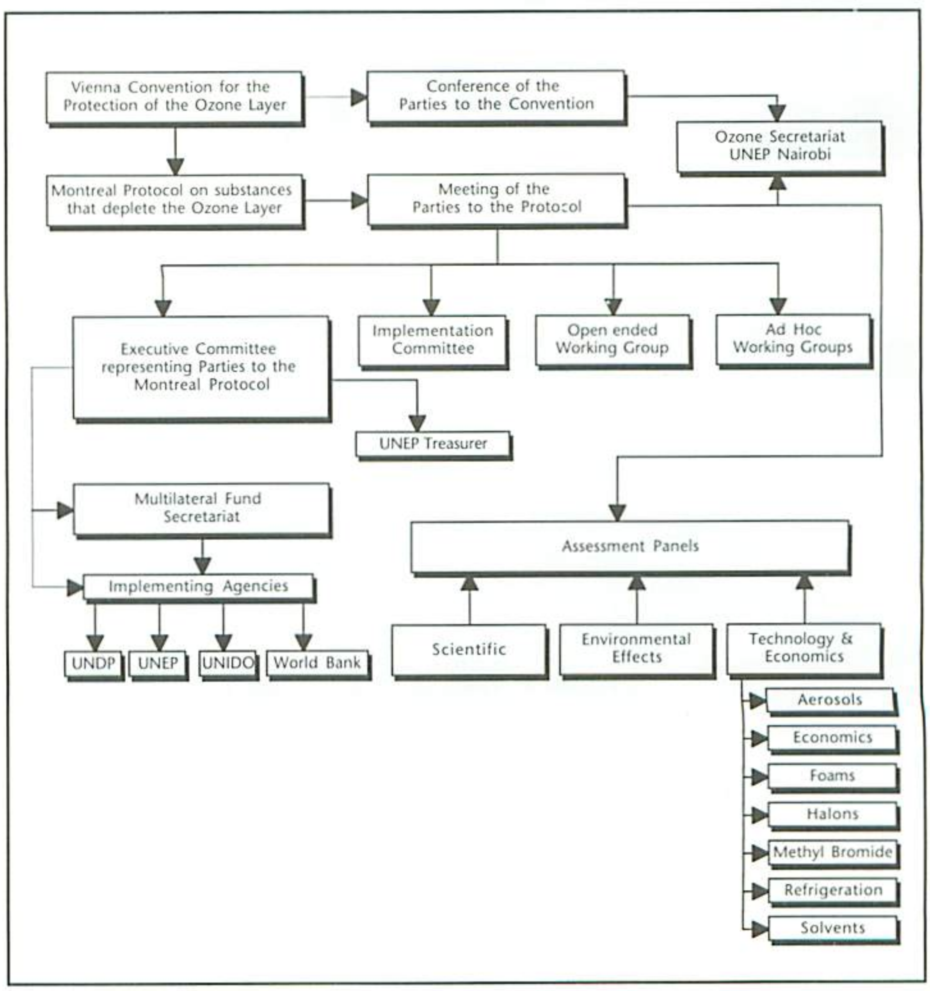
Control measures on ozone-depleting substances

At the heart of the Montreal Protocol lies the control measures it imposes on the production and consumption of ozone-depleting substances (ODS). Article 2 of the agreement defines phase-out schedules for the various categories of ODS. These have been progressively tightened with time through the agreements reached in London (1990), Copenhagen (1992) and Vienna (1995). In accordance with these schedules, the bulk of ODS – including all the substances specified in the original Protocol – were phased out completely in industrialized countries by the end of 1995. The remaining categories are scheduled for total phase-out by 2010 (methyl bromide) and 2030 (HCFCs). Developing countries, however, have rather longer phase-out periods – see below.

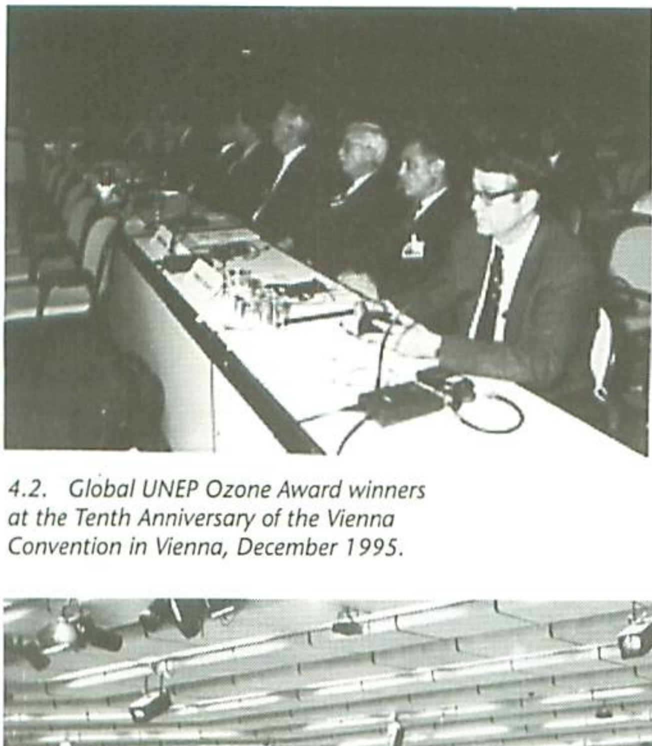
Production is defined as total production minus amounts destroyed and used as chemical feedstock and process agents. Consumption is defined as production plus imports minus exports. Trade in recycled and used ODS is not included in the calculation of consumption, in order to encourage recovery, reclamation and recycling. 'Essential uses' for which no alternatives have yet been identified are exempt from the controls; the main exemption is currently for CFCs for use in metered dose inhalers for asthma.

The Protocol includes restrictions on trade with non-parties to the treaty. These were designed in order both to encourage countries to join, and to prevent production of ODS transferring to non-parties to escape the controls. Parties were required to ban the import

Fig. 4.1. Organigram of the Montreal Protocol Implementation



1993 Parties to the Montreal Protocol agree not to allow any exemptions for the production of halons beyond the 1994 phase-out deadline agreed in Copenhagen, and approve a budget of $510 million for the Multilateral Fund for 1994–1996.



UNEP, Ozone Secretariat

4.2. Global UNEP Ozone Award winners at the Tenth Anniversary of the Vienna Convention in Vienna, December 1995.

UNEP, Ozone Secretariat

4.3. Plenary of the Seventh Meeting of the Parties to the Montreal Protocol.

of (CFCs and halons from non-parties from 1990 (one year after the Protocol came into force); exports to non-parties were banned from 1993. Imports of goods containing CFCs (e.g. refrigerators) were also banned from 1993. As new substances have been added to the control schedules, the trade provisions have been gradually extended, although they do not yet cover HCFCs, HBFCs or methyl bromide. The trade restrictions are not applicable against a non-party which is nevertheless in compliance with the control schedules.

Institutions and procedures

The main decision-making body of the Montreal Protocol is the Meeting of the Parties, which can amend the Protocol's text and adjust its control schedules. Meeting annually, it reviews the control measures at least every four years on the basis of available scientific, environmental, technical and economic information. The Open-Ended Working Group of the Parties meets between full sessions to develop and negotiate recommendations for the full Meeting.

The first Meeting established advisory panels bringing together experts from science, industry, governments and non-governmental organizations. These currently comprise:

- The Scientific Assessment Panel, responsible for reviewing scientific knowledge on ozone depletion;
- The Environmental Effects Assessment Panel, surveying information on the impact of ozone depletion and UV-B irradiation; and
- The Technology and Economic

1994 Total phase-out of halons in developed countries. Based on data submitted to the Ozone Secretariat in 1994, developed country parties' consumption of CFCs and halons dropped by about 50% between 1986 and 1992, while consumption rose for all controlled substances except halons.

Assessment Panel (TEAP) analysing the technical options for and the economic costs of controlling the use of ODS, including reviewing applications for essential use exemptions; the TEAP functions largely through subsidiary technical options committees, which currently cover aerosols, economic options, foams, halons, methyl bromide, refrigeration and solvents.

The reports the panels have produced for the key meetings of the parties have proved crucial in informing the decisions ultimately taken, including the adjustments to the control measures and the amendments to the Protocol.

The Implementation Committee of the Protocol consists of representatives of ten parties, two from each of the five United Nations regions. It reports cases of non-compliance to the full meeting and recommends courses of action; these can include providing technical or financial assistance, issuing cautions, or suspending the party from the Protocol. The Ozone Secretariat, part of UNEP and based in Nairobi, provides support for both the Montreal Protocol and the Vienna Convention and publishes the Handbook for the Ozone Treaties containing the current status of both the Convention and the Protocol.

Developing countries and the Multilateral Fund

A key feature of the Montreal Protocol is its treatment of developing countries. Article 5 permits a developing country with consumption lower than a specified limit (an 'Article 5 country') to delay for ten years its compliance with the control measures set out in Article 2, 'in order to meet its basic domestic needs'. The parties agreed precise control schedules for the various categories of ODS in 1995, with most substances being scheduled for phase-out by 2010.

Article 10 of the Protocol provides for a financial mechanism to meet the incremental costs of these countries in phasing out ODS. The parties accordingly established the Multilateral Fund as an interim mechanism in 1990 and in its final form in 1992. Industrialized country parties contribute to the Fund according to the standard UN scale of assessment. Funding was set at $240 million for 1991–1993 and $510 million for 1994–1996. About 80% of this has been collected, with the arrears originating largely from the 'countries with economies in transition' (the states of central and eastern Europe and the former Soviet Union), currently experiencing severe economic difficulties.

The Multilateral Fund has its own Secretariat in Montreal and is directed by its Executive Committee, comprising representatives of seven Article 5 and seven non-Article 5

UNEP/IE, Ozone Secretariat

4.4. Technical skills training for ODS phase-out.

4.5. Training on the latest technical equipment for developing countries, supported by the Multilateral Fund.

UNEP/IE, Ozone Secretariat

***1995** Tenth anniversary of the Vienna Convention celebrated in Vienna. Montreal Protocol assessment panels report that phase-out is well advanced in most developed countries and that developing countries are also making progress, though consumption of controlled substances is increasing in some. Meeting in Vienna, the parties to the Protocol agree to tougher phase-out schedules for HCFCs and methyl bromide for developed countries, agree schedules for all substances for developing countries, and consider likely cases of non-compliance in some transition economies. European Union achieves total phase-out of CFCs.*

countries selected by the annual meeting of the parties to the Protocol. The Multilateral Fund operates through four implementing agencies, each with slightly different roles:

- UNEP's Industry and Environment Programme Activity Centre provides clearing-house functions and helps prepare country programmes for low-consuming developing countries;
- The United Nations Development Programme (UNDP) organizes demonstration and investment projects, technical assistance and feasibility studies;
- The United Nations Industrial Development Organization (UNIDO) prepares and appraises investment project proposals and implements phase-out schedules at plant level;
- The World Bank, which disburses almost half of the total funding, concentrates on large-scale phase-out and investment projects at plant and country levels.

Each Article 5 country, assisted by one of these agencies, prepares a country programme, showing its present and projected use of ODS and identifying opportunities for reduction. The 'incremental costs' which countries can claim include the costs of conversion to alternative technologies and substances, patents, designs and royalties, training and research and development. Recycling controlled substances and modifying or replacing equipment can also be eligible, and the Multilateral Fund's Executive Committee has discretionary powers to include costs other than those listed. The Committee approves both the country programmes and subsequent proposals for investment projects and institutional strengthening. By 30 June 1996, a total of \$477 million had been allocated to eliminate a projected 70,000 ODP-tons of ODS (about one third of the total consumption of developing countries).

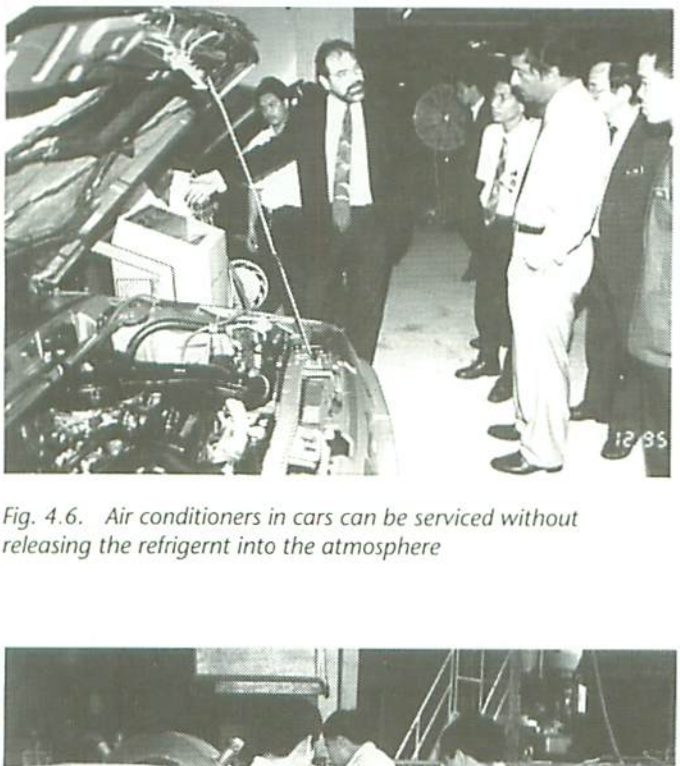


Fig. 4.6. Air conditioners in cars can be serviced without releasing the refrigernt into the atmosphere

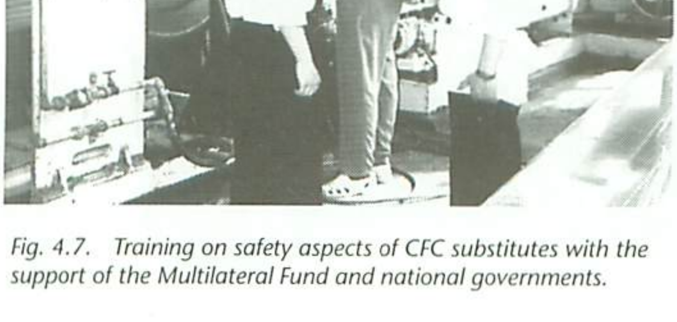


Fig. 4.7. Training on safety aspects of CFC substitutes with the support of the Multilateral Fund and national governments.

1996 *Total phase-out of CFCs, carbon tetrachloride and methyl chloroform in developed countries, and of HBFCs in all countries. Meeting of the Parties to the Montreal Protocol scheduled to discuss next three-year (1997–1999) replenishment of the Multilateral Fund, the possible extension of trade restrictions to methyl bromide, and the problem of illegal trade in CFCs.*

5 • The Impact of the Ozone Regime

The record of the ozone regime

By June 1996, a total of 159 countries had ratified the 1985 Vienna Convention and 157 the 1987 Montreal Protocol; 111 had ratified the 1990 London Amendment and 57 the 1992 Copenhagen Amendment. Production and consumption figures for the various controlled substances have changed dramatically. By the end of 1994 (the latest date for which full data is available), production and consumption of the original controlled CFCs and halons had fallen by 93% in industrialized countries, seeming well on schedule for phase-out by the end of 1995. Although both production and consumption had increased in developing countries, as expected and allowed by the Protocol, overall world production had declined by about 75% from the base year, 1986.

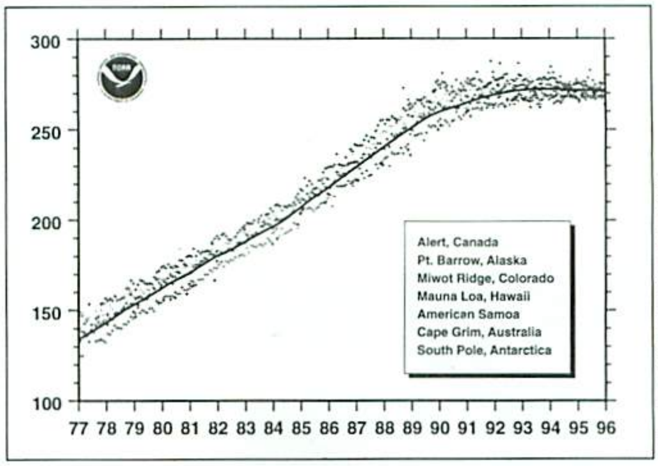
The growth in concentrations of the major ozone-depleting chemicals in the atmosphere has clearly slowed. Total organic chlorine (the best measure of the potential for ozone depletion) in the lower atmosphere increased by 60 parts per trillion (ppt) per year (1.6%) in 1992, compared to 110 ppt/year in 1989. Scientists believe that peak total chlorine and bromine loading in the lower atmosphere may already have occurred in 1994–1995 and atmospheric concentrations of some CFCs are now falling.

Concentrations in the upper atmosphere, where the ozone layer is located, lag by about three to five years, giving an anticipated peak rate of global ozone depletion in 1998–2000. Compared to the late 1960s, maximum ozone losses are predicted to be 12-13% at northern mid-latitudes in winter and spring, and 6–7% in summer and autumn, with about 11% losses in southern mid-latitudes round the year. Further volcanic eruptions or particularly cold Arctic winters could lead to greater losses in particular years. If the Montreal Protocol control regimes for ODS are fully implemented, global ozone levels should gradually recover after 2000, with the Antarctic ozone hole finally closing around the middle of the next century.

Alternatives to ozone-depleting substances

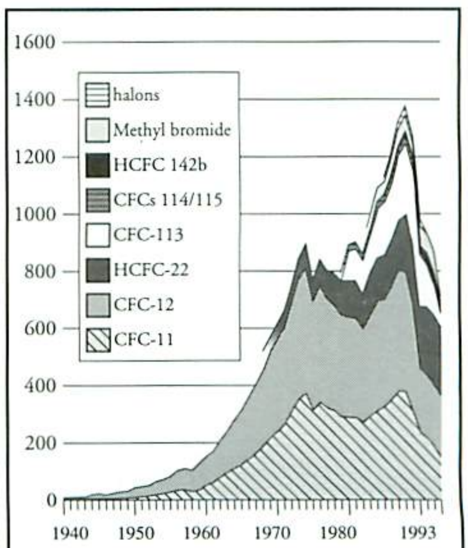
This success story of international environmental diplomacy has proved possible because science and industry, stimulated by the clear objectives of the Montreal Protocol, have been able to develop and commercialize alternatives to ozone-depleting chemicals. These take the form not only of replacement substances but also of alternative, or 'not-in-kind', technologies.

In general, industrialized countries have found ending their use of CFCs much easier than was originally anticipated. Not-in-kind substitutes have proved particularly important in the electronics sector. The foam-blowing sector has made use of water, carbon dioxide and hydrocarbons, as well as HCFCs. The refrigeration and air-conditioning sector has largely used HCFCs as alternatives, but new equipment is increasingly using non-ozone depleting hydrofluorocarbons (HFCs), ammonia (the chemical used in the very first refrigerators) or hydrocarbons, as in, for example, the 'greenfreeze' domestic refrigerator



Elkins et al., 1993; Montzka et al., 1996

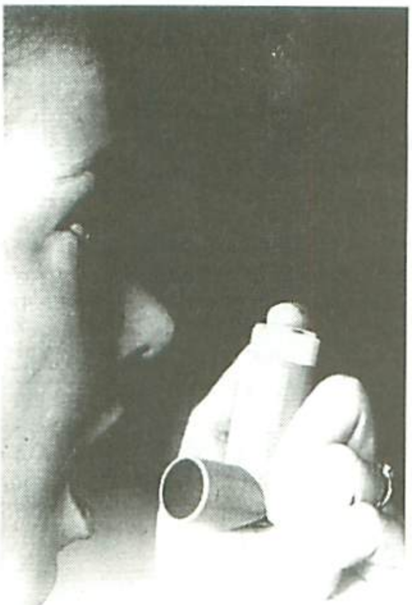
Fig. 5.1. Concentrations of CFC-11 at observing stations in the northern and southern hemispheres updated through the end of 1995 showing the levelling off in the 1990s. Points represent monthly means; the solid line is an estimate of the global tropospheric mean over time.



Sources: Methyl bromide data: Methyl Bromide Global Coalition: other ODS; AFEAS (Alternative Flourcarbons Environmental Acceptability Study), based on an independent survey of 19 companies excluding China, India and the CIS.

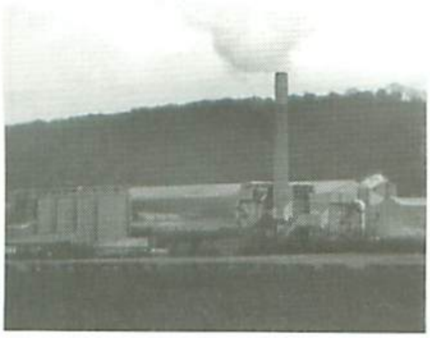
Fig. 5.2. Worldwide production of ODS, 1940-1993 (1000 tons)

1997 Tenth anniversary of the Montreal Protocol due to be celebrated in Montreal. Meeting of the Parties to the Montreal Protocol scheduled to review controls on methyl bromide.



UNEP/IE

5.3. Metered Dose Inhalers (MDIs) for therapy of respiratory diseases. MDIs use CFCs as a propellant and to dissolve the medication. MDIs are now being reformulated with CFC substitutes.



UNEP/IE

5.4. The Cement kiln is one of the ODS destruction technologies approved by the Parties.

promoted by Greenpeace. Stockpiling, or 'banking', in which CFCs have been produced before phase-out for use afterwards, has helped to extend the development and testing period.

Consumers have also used banking to provide extra time to develop substitutes for halons for firefighting. Other extinguishing agents such as carbon dioxide, water, foam and dry powder are now widely used. Alternative approaches, such as good fire prevention practices, use of fire-resistant materials and appropriate designs for buildings have significantly reduced the need for halon systems, and total phase-out was achieved smoothly by the end of 1993.

Phase-out efforts in industrialized countries are now concentrating on HCFCs and methyl bromide. Parties to the Montreal Protocol must ensure that HCFCs are used only as direct replacements for other ODS where other more environmentally suitable alternatives are not available. HCFCs were critical in meeting the early CFC phase-out goals, but are generally considered much less important for new equipment available in the medium and long-term.

The phase-out of methyl bromide is a more difficult issue. This is partly because it concerns a largely different set of producers and consumers to those involved in fluorocarbons, and also because alternatives are less easily available. The major use is in agriculture, mainly for fumigation to control pests and weeds; such treatment is often required by importers. UNEP's Methyl Bromide Technical Options Committee could not identify a technically feasible alternative for a mere 10% of 1991 methyl bromide use – though opinions diverged widely on the possible speed and costs of phase-out. Many countries have already subjected the chemical to controls in any case because of concerns about toxicity. In 1995 the parties agreed a control schedule, with ultimate phase-out by 2010. Use for quarantine and pre-shipment purposes is exempted from the controls, however, and the possibility remains of a further 'critical agricultural use' exemption after total phase-out.

New challenges

The 1995 Vienna Meeting marked the end of the initial phase of the ozone regime, which concentrated on identifying ozone-depleting substances, agreeing on control measures and phasing out substances in industrialized countries. Attention is now turning increasingly to issues of implementation in developing countries and countries with economies in transition.

The ozone regime now faces its first cases of non-compliance by some eastern European and former Soviet states. The Russian Federation, for example, has stated that it needs until the year 2000 to phase out CFCs, due to its current economic difficulties. Resources are available for phase-out of ODS in these transition economies from the Global Environment Facility, created in 1991 to provide finance for environmentally sustainable development. The Facility has so far approved $90 million worth of ozone-related projects.

The second new problem is the growth of illegal trade, which usually follows any decision to ban the use of a substance. In areas where CFC replacements (or the costs of new technology) have proved more expensive than the originals, a black market has developed. The problem is most acute in the United States, where the CFC excise tax introduced to encourage phase-out created incentives for illegal import of CFCs. The United States authorities have, however, responded vigorously to the problem and have indicted several individuals on counts of smuggling CFCs, and evading federal excise taxes. The European Union has also put in place regulations to control illegal trade.

2010 *Total phase-out of methyl bromide in developed countries, and of CFCs, halons and carbon tetrachloride in developing countries.*

2015 *Total phase-out of methyl chloroform in developing countries.*

6 • The Future of the Ozone Regime

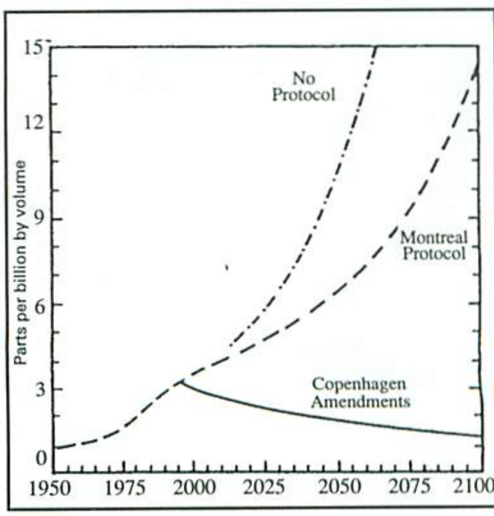
The Montreal Protocol is widely regarded as one of the most effective existing international environmental treaties. It has proved to be a flexible but robust regime, evolving over time in response to new developments in science and technology.

In the mid-1980s the international debate demonstrated considerable doubt over the extent and causes of ozone depletion and the feasibility of action. Just ten years later, the Meeting of the Parties in Vienna in December 1995, marking the tenth anniversary of the original Vienna Convention, agreed the third major set of revisions to the control schedules established in 1987. CFCs, whose production levels under the original agreement were still to have been 80% of 1986 levels, should now have been phased out completely in industrialized countries. Production of halons, which was simply to have been capped under the original agreement, ceased at the end of 1993 in these countries. Other chemicals not even thought of as ozone-depleting substances a decade ago have been brought under the coverage of the agreements and their own control schedules progressively tightened.

The Montreal Protocol has been widely hailed as a model for future international environmental agreements. The progress of the negotiations in many ways provides a model for international treaty negotiation, fully involving participants from all key groups. The flexibility built into the Protocol in the form of its review process for targets and amendments has allowed continuous evolution to respond to changes in both scientific evidence and technological developments. The limits on supply imposed by the control schedules have encouraged the rapid development of cost-effective alternatives, which in turn has helped to reduce demand.

Any effective international agreement in the modern world needs to recognize the special needs of developing countries. In the Montreal Protocol this has taken the form of the provision of financial assistance and technology transfer, the decision-making procedures which allot particular weights to Article 5 countries, and the grace period before implementation of the phase-out schedules. Finally, the evolving phase-out schedules and the trade provisions have encouraged newly industrializing countries to move out of old technology and accelerate their own phase-outs even when not required to do so under the terms of the agreement.

Perhaps the most important feature of the ozone regime is the way in which it has brought together an array of different participants in pursuit of a common end. Scientists have provided the information, with steadily increasing degrees of precision, on the causes and effects of ozone depletion.



Report of the UNEP Scientific Assessment Panel (1994)

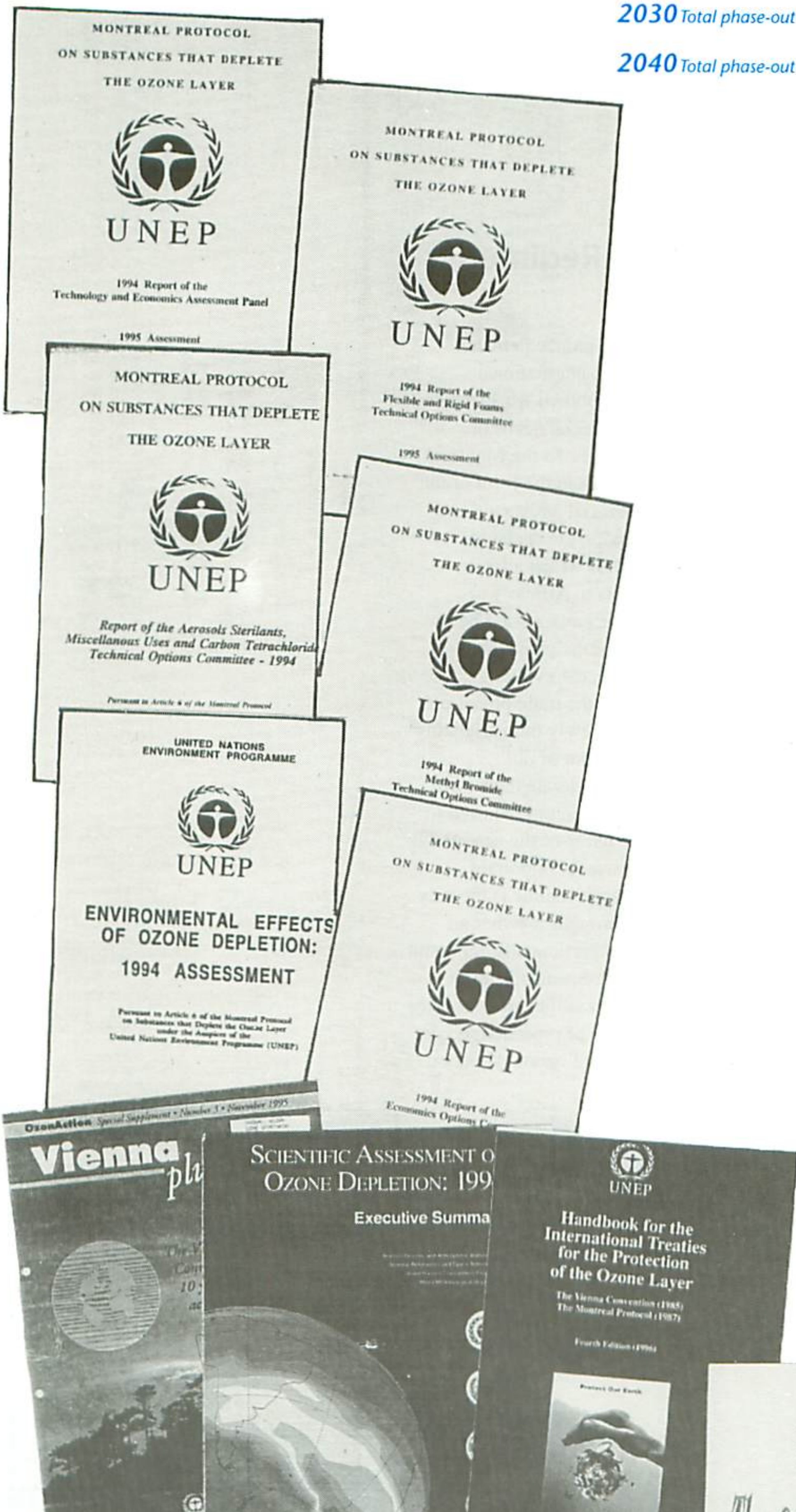
Fig. 6.1. The measured chlorine loading of the atmosphere (since 1950) and future projections, according to the various amendments to phase out CFCs and other ozone depleting substances.

2030 *Total phase-out of HCFCs in developed countries.*

2040 *Total phase-out of HCFCs in developing countries.*

Industry, responding to the stimulus provided by the control measures, has developed alternatives more rapidly and more cheaply than first thought possible, and has participated in the debates over further phase-out. Non Governmental Organizations (NGOs) and the media are the essential channels of communication, and education, with the peoples of the world in whose name measures are taken. In the early years, in particular, they were instrumental in spurring decision makers to take decisive action, and still help to maintain pressure for further measures. Governments have worked well together in patiently negotiating agreements acceptable to a range of countries with widely varying circumstances, aims and resources – and have showed courage and foresight in putting the precautionary principle into effect before the evidence was entirely clear. And throughout its history, UNEP has provided both the catalyst for action and the means of agreeing and implementing it – the global institution that is required to meet a truly global problem.

The leadership and vision of the original negotiators in Vienna and Montreal resulted in a treaty that worked - that halted and tuned back the progressive deterioration of the Earth' protective ozone layer. The same leadership and vision will still be needed as the international community turns its attention to meeting the new challenges faced by the international ozone regime in restoring the stratospheric ozone layer once more to full health.



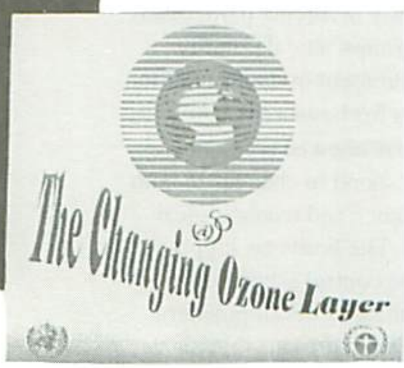


Fig. 6.2. Ozone Publications

The thin layer of ozone in the stratosphere, 10 to 50 Kms above the surface of the earth, absorbs all but a small fraction of the harmful ultra-violet (UV-B) radiation from the sun. An excess of UV-B can cause skin cancers and eye cataracts, damage plant and animal productivity and materials and have an impact on climate.

Scientists assumed in the early 1970s that man-made halocarbon chemicals - compounds containing chlorine, fluorine, bromine, carbon and hydrogen - could reach the stratosphere and destroy the ozone layer through chemical reactions. They warned of the likely damage to the ecosystems of the Earth if we continued the consumption and emission of these chemicals, which have found many uses in aerosols, refrigeration systems, fire fighting equipment, foams etc.

Many were initially sceptical of these theories but scientific observations in the 1980s, particularly the discovery of the Antarctic ozone hole in 1985, convinced governments of the need to take urgent action if the Earth was to be saved from a catastrophe. The Vienna Convention of 1985 and the Montreal Protocol of 1987 with its Adjustments and Amendments of 1990, 1992 and 1995 are the response of the world to the ozone crisis.

It is now acknowledged that these international agreements have succeeded in curbing the consumption of ozone-depleting chemicals by involving almost all governments (160 at present) of the world in an unprecedented cooperative venture. Scientists have now predicted that, given the continued implementation of these agreements, the ozone layer will start recovering by the year 2000. Full recovery will not take place for another fifty years, due to the long life of chemicals already released.

This book details the stirring story of international cooperation under the leadership of the United Nations Environment Programme. The agreements brought together a vast array of players: scientists, technologists, industrialists, public servants, journalists, NGOs, diplomats and activists on a global stage. They have come together, cutting across the North-South, rich-poor divide to avert a danger to the Earth. Readers should find a ray of hope and a way forward in this effort to save the ozone layer.

Ozone Secretariat
United Nations Environment Programme
P.O. Box 30552, Nairobi, Kenya
Tel: (254-2) 623851. Fax: (254-2) 623913
E-mail: Ozoneinfo@unep.org
Home Page : http://unep.org/unep/secretar/ozone/home.htm

ISBN 92-807-1390-6